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A clustering based genetic algorithm approach to flexible job shop scheduling problem

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1-Introduction

Nowadays in competitive industrial environment, necessity to production in high volume and with high quality causes conditions in which companies have to implement new production methods such as *Just in time* or *lean manufacturing systems*. However flexible job shop problem is a modified version of classical job shop problem. It has been proved that this problem is strongly N-P hard. So solving this problem in reasonably computational time by implementing the exact solution methods is almost intractable. So in recent years many heuristic and meta-heuristic approaches have been introduced and developed to solve this problem. Hurink et al (1994) [1] have presented a tabu search method for this problem. Also Dauzere-Peres and Pauli (1997) [2]have implemented a tabu search method extending the disjunctive graph representation for the classic job shop problem by consideration the assignment of different operations to available machines. Mastrolilli and Gambardella (2000) [3] proposed a tabu search procedure with effective neighborhood search method for solving the problem. In recent years many various techniques have been introduced to solve the Flexible job shop problem. For instance, Brandimarte (1993) [4] has proposed a heuristic approach. In his heuristic, sequencing of operations is determined firstly and then assignment of operations to machines using dispatching rules is done. Also a genetic approach has been developed to solve the problem. Many hybrid genetic algorithms are proposed in last decade, Such as Kacem et al (2002) [5], Jia et al. (2003) [6], Ho and Tay (2004) [7], Pezzella et al(2008) [8],Gao et al (2008) [9] which have proposed the hybrid genetic and variable neighborhood descent algorithm for this problem. The purpose of Research proposed by Piroozfard et al [10] is to present a multi-objective flexible job shop scheduling problem with the objectives of minimizing total carbon footprint and total late work criterion, simultaneously, as sustainability-based and classical-based objective functions, respectively. Also In order to solve the presented problem effectively, an improved multi-objective genetic algorithm is proposed to obtain high quality non-dominated schedules. Also Karimi et al. [11] have incorporated the transportation times between the machines into the flexible job-shop scheduling problem using two mixed integer linear programming models. Then they have solved the proposed method by implementing an adaptation of the imperialist competitive algorithm hybridized by a simulated annealing-based local search. Gao et al. [12] have addressed flexible job-shop scheduling problem with fuzzy processing times and then an improved artificial bee colony (IABC) algorithm is proposed for FJSP cases defined in existing literature and realistic instances in remanufacturing where the uncertainty of the processing time is modeled as fuzzy processing time. Moreover, a multi-resource-constrained flexible job shop scheduling problem that is very common in semiconductor manufacturing, precision engineering, and many other modern industries is investigated by Gao and Pan [13]. They proposed a novel algorithm called the shuffled multi-swarm micro-migrating bird optimization (SM^2-MBO) algorithm to solve the problem, optimally. Ahmadi et al. [14] developed two evolutionary algorithms, NSGA-II and NRGA in order to stable scheduling of multi-objective problem in flexible job shop scheduling with random machine breakdown.

Actually in flexible job shop there are some jobs should be processed. Each job consists of some operation which naturally should be done by a given and deterministic sequence. In this problem there is more than one machine which each operation can assign to it in order to be processed. The processing time of each operation on each machine is deterministic. Also all the machines are available at time zero. The problem is assigning the operations into machines in such way a certain objective function be minimized. In presented paper the objective which is considered as an objective functions makespan. In other words, the minimization of the last operation's finished time will be desirable in presented paper. By these considerations the flexible job shop scheduling problem can be defined as follow:

- There are n jobs each of them is independent from another and can be processed simultaneously.
- Each job i has its own operation sequence denoted by $J_i = \{O_{1i}, O_{2i}, ...O_{n_i i}\}$ where O_{ki} denotes the k 'th operation of i 'th job.
- There are m equivalent machines which are available at time zero. But one machine can process only one operation at the same time.
- For each operation O_{ki} there is a set of machines capable of performing this operation. The set is denoted by M_{ki}, $M_{ki} \subseteq \{1,...,m\}$.
- The processing time of operation O_{ki} on machine j is deterministic and can denoted by t_{kij}.
- The interruption of an operation during its processing time should be avoided.
- The objective is finding a schedule with shortest makespan.

In this paper a genetic algorithm by novel search methods has been proposed to solve the flexible job shop problem. The rest of presented paper is organized as follow: In section 3 the proposed solution method will be introduced and discussed. In section 4 the proposed methods efficiency will be verified and the data analysis will be done. At last section 5 will conclude this article.

2- PROPOSED GA

As stated previously the flexible job shop problem is a NP-hard problem [15]. In the recent years many studies have been conducted to solve these complex problems optimally. Especially many heuristic and meta-heuristics have been proposed to solve the flexible job shop problem ([16], [17], [18]).

Accordingly in this paper a new cluster based genetic algorithm approach has been developed. Moreover, some new search strategies are introduced in order to explore the solution space more efficiently. The imperialist competitive algorithm is an efficient meta-heuristic evolutionary algorithm which starts with a population of solutions, any of them called a country. These countries are divided into two basic groups. The best answers or the powerful countries become the imperialists and the colonies consist of rest of the solutions. In this paper, a new meta-heuristic hybrid algorithm based on genetic and imperialist competitive approaches is implemented in order to find the optimal or near- optimal solution. Figure 1 demonstrates a schematic view of proposed algorithm, in which colonies move toward the best near country instead of moving toward the imperialist. Literally, this process prevents the algorithm from reaching a local optimal solution. The proposed method consists of two competition types.

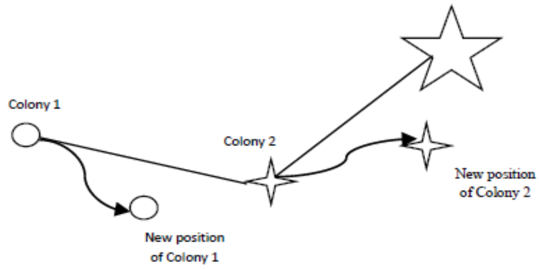


Fig1- Schematic view of proposed method

2-1- solution representation

During the genetic approach which is introduced in this paper, a candidate solution is represented by a chromosome consists of two sections. The first half denotes the sequence of the operations which should be processed on different machines and the second denotes the assignment of different operations available machines. Let consider the following chromosome as an example.

2	3	1	4	1	3	2	1	10

This chromosome states that the operation 2 is the first operation which should be processed on machine 1. The order of other operations is operation 3 on machine 3, operation 1 on machine 2 and operation 4 on machine1. The last gene of the chromosome represents the fitness function of corresponding chromosome. A set of chromosomes at time "t" is called the solution space and each member of a solution space is evaluated by a score function. This evaluation helps to choose the best string as a parent.

2-2- initial population

In every meta-heuristic approach it is necessary to determine the suitable population size. It is clear that a high valu e of

$$N_{POP} = 1.65 \times 2^{0.21 \times LC} \qquad (1)$$

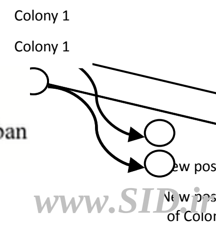
population size results in sluggish process in GA and a low value will cause less possibility of crossover operator. Golberg [18] has suggested the equation 1 to population size determination.

Where
LC is the strings length.

This equation is suggested for binary coding and maximum length of 60 strings. In this paper equation 1 has been used for preliminary population size determination. However in order to applying crossover operators the nearest multiple of 4 to this number has been selected.

2-3- evaluation

Basically, genetic algorithm is introduced to maximization problems solving. Therefore, for maximization problems the objective function can be used as a fitness function, but for minimization problems a suitable fitness or score function should be used. Equation 2 is suggested as a



fitness function where corresponding problem is a minimization problem.

$$f_i(t) = e^{-\Phi_i} \qquad (2)$$

Where, Φ_i is objective function value.

By the way, in this paper by applying suitable matrix operators, the objective function value is employed as a fitness function.

2-4- selection and crossover operators

The main contribution of presented paper is applying the crossover operators on groups of strings. Actually the solution space clustering is performed in order to maximize the search efficiency. Here we consider each four strings as a batch or cluster. We apply the crossover operators based on the best string in each batch on other members of corresponding group. Two methods have been used to apply crossover operator including: reversing the best string (figure 1); two point crossover (figure 2). The crossover operators may cause the missing of an operation number as observed through the new strings. In other words by applying these operators an unfeasible solution may be obtained. The strategy used to treat these solutions is correction which means the mutation crossover is used to correct the infeasible strings. However this strategy may increase the computational time of problem.

Parent:	2	3	1	4	1	3	2	1	10
child:	4	1	3	2	1	2	3	1	10

Figure 1- reverse the string

parent1:	2	3	1	5	4	4	3	2	1	5	12
parent2:	2	3	1	5	4	2	4	1	5	3	13

Child1:	2	3	1	5	4	4	4	1	1	5	14
child2:	2	3	1	5	4	2	3	2	5	3	11

Figure 2- two-point crossover

So, the pseudo code for proposed meta-heuristic can be written as follow:

1-start

2-Input the initial parameters such the number of iterations as n_i *and Populationsize*

3- $n = 0;$

4-Create the initial population randomly.

5- $n = n + 1;$

6-Sort the strings based on their objective function values.

7-Divide the strings into groups with 4 strings and for each group do these steps:

8-Produce two random binary numbers as "r" and "t"

9-For members 1 t0 3 of each groups do these steps:

-If $r == 0, t == 0$ *apply the first crossover on operation sequence.*

-If $r == 0, t == 1$ *apply the second crossover on operation sequence.*

-If $r == 1, t == 0$ *apply the first crossover on machine assignment.*

-If $r == 1, t == 1$ *apply the second crossover on machine assignment.*

10-For the last member of group apply the first crossover on operation sequence ond the second one on machine assignment.

11-Correct the infeasible solutions and calculate the objective function.

12-If $n == n_i$ *finish, else go to 5.*

3-NUMERICAL EXAMPLES

In order to verify the performance of proposed method, we compare it with a data set. The data set is proposed by Kacem et al [5]. Table1 illustrates the results.

Also we compare the results by two solution methods presented by Ho and Tay [7]. It is obvious that the proposed method have the ability to obtain better solutions in comparison with other solution methods introduced before. Equation 3 calculates the improvement percentage of proposed method.

$$\%\ improvement = \left(\frac{OF_{proposed\ GA} - OF_{Kacem}}{OF_{Kacem}}\right) \times 100 \qquad (3)$$

$population\ size = 100$

$number\ of\ iteration = 100$

$operation\ sequence\ crossover\ probability = .5$

$machine\ assignment\ crossover\ probability = .5$

The implemented initial parameters are reported as follow:
The examples are solved by MATLAB 7 software package.
Figure 3 shows an optimal or at least close to optimal solution for example I1.
The proposed method can obtain better solutions in cases 1, 2 and 4.

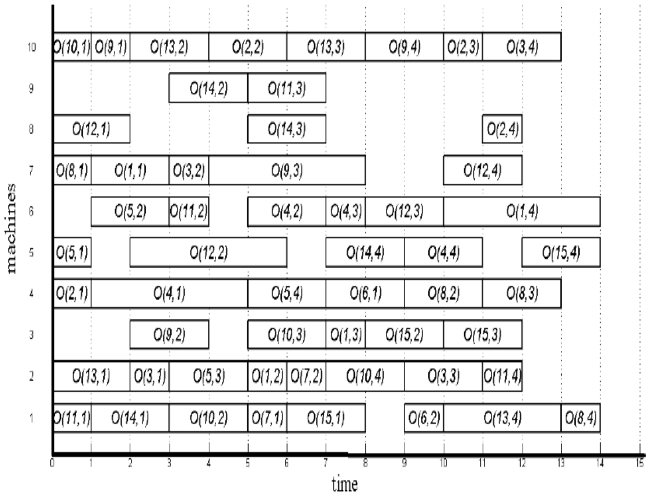


Figure 3 - solution obtained by proposed GA for I2 instance

Two essential factors should be considered in every meta-heuristic are computational time and solution quality. So we compare the proposed solution method with traditional genetic algorithm which exists in literature. Table 2 reports the results.

Table 2- solution quality and run time comparison between traditional and proposed genetic algorithms

Example no.	Run time(s) Proposed GA	Run time(s) Traditional GA	Makespan traditional GA
I_1	263	215	11
I_2	396	418	13
I_3	706	814	9
I_4	1146	1560	15

Figure 4 is implemented to illustrate this comparison in schematic way. It is clear that, the proposed method is more efficient in comparison with the other genetic algorithm proposed before. As it was pointed before, the solution space clustering results in two essential benefits. The first is local optimal areas escaping and the second is exploring the solution space more efficiently.

Table1- the results comparisons between proposed method and methods exist in literature

Example no.	job×machine	Kacem et al	CDR	GENACE	Proposed method	Improvement (%)
I_1	4×5	16	11	11	11	31.25*
I_2	10×7	15	13	12	12	20*
I_3	10×10	7	9	7	8	-
I_4	15×10	23	12	12	15	34.78*

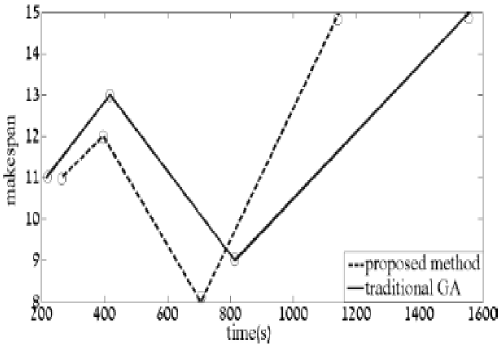


Figure 4 - schematic comparison of proposed and traditional Gas.

4-CONCLUSION

In this paper a new genetic based algorithm was presented to flexible job shop scheduling problem. In proposed method implementing various crossover methods can explore the solution space much better. Also some numerical examples are selected from literature and the proposed method efficiency was compared with other solution methods to solve flexible job shop problem. The experimental results verified the proposed methods efficiency from solution quality and computational time aspects as well. For the future research proposing new methods for searching the solution space precisely and much better will be truth worthy.

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